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DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
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Manual
No. 1110-2-2704

1 January 1999

Engineering and Design
CATHODIC PROTECTION SYSTEMS FOR CIVIL WORKS STRUCTURES

1. Purpose. This manual provides guidance for the selection, design, installation, operation, and maintenance of cathodic protection systems (CPS's) for navigation lock gates and other civil works hydraulic structures.

2. Applicability. This manual applies to all USACE Commands having civil works responsibilities.

3. Discussion. The primary corrosion control method for civil works hydraulic structures is a protective coating system, most often paint. Where the paint system and structure are submerged in water, a combination of the anodic and cathodic properties of materials, the liquid electrolyte, and external electrical circuits combine to form electrochemical corrosion cells, and corrosion naturally follows. CPS's can supplement the paint coating system to mitigate corrosion damage.

4. Distribution. Approved for public release; distribution is unlimited.

FOR THE COMMANDER:

ALBERT J. GENETTI, JR.
Major General, USA
Chief of Staff

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Chapter 1
Introduction

1-1. Purpose and Scope

This manual provides guidance for the selection, design, installation, operation, and maintenance of cathodic protection systems (CPS's) used to supplement paint systems for corrosion control on civil works hydraulic structures. It also discusses possible solutions to some of the problems with CPS's that may be encountered at existing projects.

1-2. Applicability

This manual applies to all USACE Commands having civil works responsibilities.

1-3. References

a. MIL-HDBK-1004/10, Electrical Engineering Cathodic Protection.

b. EM 1110-2-3400, Painting: New Construction and Maintenance.

c. ETL 1110-9-10, Cathodic Protecion Systems Using Ceramic Anodes.

d. CW-09940, Painting; Hydraulic Structures and Appurtenant Works.

e. CW-16643, Cathodic Protection Systems (Impressed Current) for Lock Miter Gates.

f. TN ZMR-3-05, Components of Hydropower Projects Sensitive to Zebra Mussel Infestations.

g. NACE International Standard RP0169-96, Recommended Practice, Control of External Corrosion on Underground or Submerged Metallic Piping Systems.

1-4. Background

a. General. The Corps uses CPS's in combination with protective coatings to mitigate corrosion of hydraulic structures immersed in fresh, brackish, or salt water. Protective coatings are rarely completely effective because, even on application, they contain pinholes, scratches, and connected porosity. As coatings degrade with time, these imperfections, commonly known as holidays, have a profound effect on overall coating integrity because of underfilm corrosion. CPS's, when used in conjunction with protective coatings, have been effective in controlling corrosion. CPS's consist of anodes that pass a protective current to the structure through the electrolyte environment. CPS's can be one of two types, sacrificial anode or impressed current anode. Hydrid CPS's installed on structures can contain both types of anodes to provide protective current.

(1) Sacrificial anodes, such as magnesium or zinc alloy, corrode and wear more readily than the structure to be protected because of their more negative electrochemical potential. Sacrificial anodes do not require an outside power source; rather, they provide their own power and need very little maintenance. They should be replaced whenever the anode material has been consumed, so they should be easily accessed. Sacrificial anodes are generally recommended for use with a well-coated structure with minimum chance of being damaged during its useful life.

(2) Impressed current anodes are made of durable materials that resist electrochemical wear or dissolution. The impressed current is supplied by a power source such as a rectifier. All impressed current CPS's require routine maintenance because they involve a power supply and a greater number of electrical connections than do sacrificial anodes. However, impressed CPS's can be used with bare or poorly coated structures because of the greater current capacity.

b. Locations. Since 1950, USACE has used impressed current CPS's with graphite or high-silicon, chromium-bearing cast iron (HSCBCI) anodes. The first systems were installed on the Mississippi River near Rock Island, IL, on an experimental basis. Since then, CPS's have been used widely. About 22 CPS's were installed and are currently functioning on structures on the Tennessee-Tombigbee Waterway, the Alabama River, and the Black Warrior River in the Mobile District. CPS's have been used successfully on the Intercoastal Waterway on seven sector gates in the Jacksonville District and on miter gates in the New Orleans District. Impressed current systems have also been installed on three lock gates on the Columbia River in the Northwest. Similarly, impressed current systems using both graphite and HSCBCI anodes were installed on lock gates on the Ohio River during the 1970's. However, ice and debris damages have made most of these systems inoperable. Since the early 1980's, a new type of ceramic-coated composite anode material has been used for various electrochemical processes, particularly in the electrolytic production of chlorine and cathodic protection systems, including off-shore, water tank, and groundbed applications. The mixed metal oxide ceramic-coated anodes consist of a conductive coating of iridium or ruthenium oxide (IrO2 and RuO2, respectively) applied by thermal decomposition onto specially prepared titanium substrates. The coatings are applied by spraying aqueous metallic salts onto the titanium substrates and heating to several hundred degrees Celcius. Multiple layers of coating material may be applied by the process to provide a maximum coating thickness of approximately 0.025 mm (1 mil). This type of CPS has been used at Pike Island and other locations with good results.

c. Inoperable impressed current systems. Most of the inoperable impressed current systems encountered were utilizing graphite anodes that were more than 20 years old. Only a few navigation structures have had systems that utilized sausage string cast iron anodes provided with impact protection. Properly maintained cast iron anode systems that have been in high-impact debris areas have shown good results. Graphite systems in low-impact debris areas have also shown good results.

d. Inoperable sacrificial anode systems. Zinc or magnesium sacrificial anodes provide some benefits, but typically, these anodes only protect small areas such as well-coated structures, and they experience higher consumption rates than anodes normally used in an impressed current system. In order to be beneficial, sacrificial anodes must continue to apply current to the structure. Consequently there must be periodic voltage testing, and the system must be kept optimized by anode replacement to continue its performance in accordance with acceptable criteria.

e. Solutions.

(1) Restoration of systems. Most existing inoperable CPS's at navigation structures can be restored. This approach is less expensive than installing complete new systems, and therefore should be considered first. When graphite anode strings are consumed or destroyed, they can be replaced with impact-protected cast iron anode strings or ceramic-coated wire. In many cases, anode strings can be replaced and systems can be repaired without dewatering a lock.

(2) New or replacement systems. Designers should use Guide Specification CW-16643 with this manual for new CPS installation or for complete system replacement when necessary.

f. Effective techniques. National Association of Corrosion Engineers (NACE) Standard RP0169-96 contains the recommended practice for control of external corrosion on civil works hydraulic structures. It includes criteria for both coatings and cathodic protection and should be used in conjunction with guidance in this manual and with painting design guidance in Engineer Manual EM 1110-2-3400. NACE Standard RP0169-96 should also be used as guidance unless noted otherwise, and designers should become familiar with it.

g. Resistivity policy. Cathodic protection should be provided on all submerged metallic structures. If, after performing a corrosion mitigation survey, an NACE-certified corrosion specialist or a professional engineer deems cathodic protection unnecessary due to a noncorrosive water, a statement to that effect should be prepared and sent to the district project manager as a part of the corrosion plan.

Chapter 2
Corrosion Mitigation Plan

2-1. Corrosion Protection Coordinator

Each district should designate a person who has experience and is familiar with cathodic protection techniques to serve as the district corrosion protection coordinator. Such a person may be a licensed professional engineer or a person certified as being qualified by NACE International as a cathodic protection specialist, corrosion specialist, or senior corrosion technologist. This individual will be responsible for ensuring that the CPS's are tested and optimized and that reports of the results are prepared and maintained at the district for review of system effectiveness.

2-2. Plan

a. Development. A corrosion mitigation plan should be developed by the district corrosion protection coordinator for each hydraulic structure.

(1) New projects. A corrosion mitigation plan should be developed and included in the design memorandum. For an already completed design memorandum, the plan should be developed and submitted as a supplement to the design memorandum prior to completion of plans and specifications.

(2) Existing projects. A corrosion mitigation plan should be developed and presented as an appendix in a Periodic Inspection Report for reference in subsequent inspections. Corrosion mitigation plans should consider the condition of existing structures, factors that affect the rate of corrosion, methods of corrosion control, and cathodic protection of the structure.

b. Execution. The following policy on optimization, testing, and reporting of the CPS for each structure should be followed.

(1) A survey of the structure-to-electrolyte potential, using a standardized reference cell, should be performed. Any system failing to operate in accordance with established criteria should be optimized by adjustment.

(2) A report showing the condition of the CPS's and including any plans to repair the systems should be prepared and kept at the district for review.

(3) Any inoperable CPS should be repaired as needed.

2-3. Tests and Adjustments

a. Tests, adjustments, and data collection. Tests should be performed in accordance with the corrosion mitigation plan. Rectifier voltages and currents should be recorded. There are no prescribed time intervals for testing new systems, but measurements should be taken and recorded monthly until steady-state conditions are reached. Then, based upon the judgment of the corrosion protection coordinator, tests should be performed at about 6-month intervals for a year or more, and thereafter at yearly intervals. It would be appropriate to monitor critical or strategic structures more frequently. Based upon the measurements taken, the rectifier current and voltage should be adjusted to produce either a negative polarized (cathodic) potential of at least 850 mV with the cathodic protection applied or other minimum cathodic polarization such as 100-mV polorization as described in NACE RP0169-96 for steel and cast iron piping. This potential should be achieved over 90 percent of each face of each gate leaf. Readings should not exceed a polarized (cathodic) potential of 1200 mV at any location. Acceptance criteria for CPS's should be as defined in NACE Standard RP0169-96 unless otherwise noted in this manual.

b. Reports. Reports should be prepared and kept at the district. These reports should be presented in a format similar to that in the Appendix A sample and table for a miter gate, showing measurements taken and data obtained. For other types of installations, the report should be modified to show similar data applicable to the respective installation. This report should be completed yearly not later than December.

c. Data. The data accumulated in these reports should be retained to provide a database for consideration of possible improvements to CPS techniques. The current corrosion deterioration status of the structures should be maintained.

Chapter 3
Expert Assistance

3-1. Background

Some Corps districts and laboratories have long been involved in planning, designing, procuring, installing, testing, operating, and maintaining various types of CPS's for navigation structures. Expertise is available to assist USACE elements in any of the above areas on a cost reimbursable basis. For further information concerning USACE expert assistance in the above-mentioned areas, please contact CECW-ET, HQUSACE.

3-2. Expertise

District personnel who have limited experience and expertise in CPS's are encouraged to seek assistance from other districts and/or laboratories through their Corrosion Protection Coordinator.

3-3. Assistance

The specific areas of assistance include initial planning, preparation and/or review of design and solicitation packages, review of design submittals, review of shop drawings or contract changes, training, and preparation of corrosion mitigation test plans. Assistance is also available, in troubleshooting, restoring, testing, and adjusting and optimizing CPS's.

3-4. Element Responsibility

USACE elements will be responsible for ensuring that all solicitations comply with current procurement policy, including consideration of the offeror′s experience and qualifications. Although the procurement method selected for any given project is at the discretion of the responsible element, the intent of this manual is to provide guidance so that all contractors in cathodic protection have qualifications which, as a minimum, meet the requirements in Chapter 6.

Chapter 4
Testing and Optimizing

4-1. Equipment and Personnel

Test equipment should consist of a fresh and calibrated copper-copper-sulfate reference cell, a submersible connection, cabling suitable for immersion use, and a high-impedance voltmeter capable of measuring polarized potentials with the CPS on. Sensitivity should be more than 5 meg-ohms per volt. The reference electrode should be placed in the electrolyte adjacent within 200 mm to the face of the gate at each test point. All tests should be supervised by an NACE-certified corrosion specialist, senior corrosion technologist, or cathodic protection specialist, a licensed corrosion engineer, or a Corps of Engineers representative assigned and qualified to do this work.

4-2. Optimizing System

Data collected during the test should be reviewed, and any necessary adjustments should be made. The system should be properly optimized by adjusting the rectifier until 90 percent of the potentials fall within the range of polarized (cathodic) potential of between negative 850 mV and negative 1200 mV or 100-mV polorization according to NACE RP0169-96. A report on test results should be prepared and retained at the district. Research and development work on low-cost remote monitoring systems has been performed recently to increase reliability, extend service life, minimize maintenance requirements, and automate the CPS testing, evaluation, and diagnostic procedures to reduce the life-cycle cost of CPS's. For further information concerning the remote monitoring system, please contact CECW-ET, HQUSACE.

Chapter 5
System Selection

5-1. Corrosion Protection

Corrosion occurs on all metallic structures that are not adequately protected. The cost of replacing a structure which may have been destroyed or weakened due to excessive corrosion is substantial but avoidable, and means should be taken to prevent or mitigate this added cost through cathodic protection. In addition to preparing and applying protective coatings to the surface of a structure, a technique used to further prevent corrosion is to apply a protective current to the structure surface which contacts an electrolyte. This technique prevents or reduces the rate of surface corrosion by making the surface cathodic in the presence of other metals contacting the electrolyte.

5-2. Types of CPS's

a. Sacrificial CPS. This system helps reduce surface corrosion of a metallic structure immersed in an electrolyte by metallically coupling a less noble, i.e., more negative, metal with the structure. This system is based on sacrificing the more negative anodic metal to save the structure from deterioration by corrosion. Usually the anodic metals used are composed of zinc or magnesium.

b. Impressed current CPS. This system uses direct current applied to an anode system from an external power source to drive the structure surface to a state that is cathodic with respect to other metals in the electrolyte. Two types of anodes can be used; string anodes are installed either adjacent to or on the structure, and button anodes are installed on the structure. Both types must be isolated from the surface of the structure. Civil works systems are usually impressed current systems.

5-3. CPS Selection

When selecting which type of system to use, the designer should consider the size of the structure to be protected and past project experience in operating and maintaining both types of systems. Sacrificial anode systems on large structures such as gates deteriorate rapidly and become ineffective. However, a properly maintained impressed current system can last 10 to 30 years on the same structure.

a. Basis for selecting an impressed current system.

(1) Can be designed for a wider range of voltage and current applications.

(2) Higher ampere-years can be obtained from each installation.

(3) One installation can protect a more extensive area of the surface of the metallic structure.

(4) Voltage and current can be varied to meet changing conditions. This provides an operational flexibility that is very desirable to increase protection of the surface coating.

(5) Current requirement can be read and monitored easily at the rectifier.

(6) System can be used for protecting bare or poorly coated surfaces of metallic structures.

b. Basis for selecting a sacrificial anode system.

(1) External power source is not required.

(2) Installation is less complex since an external power source, including rectifier, is not required.

(3) This system works very well when resistivity is low, the structure is well coated, easy access to the structure is available, and significant deterioration of coating (paint) is not expected within 5 to 10 years.

(4) This system is easier to install on moving complex structures such as tainter valves where routing of cables from an impressed current system could present a problem.

c. Basis for not selecting a sacrificial anode system.

(1) Current output is limited. It has limited driving potential, therefore the protection for the bare steel area from each anode is limited.

(2) Sacrificial anode systems generally cannot be justified in water media when large surface areas of a poorly coated metallic structure require protection.

(3) Installation can be expensive. A greater amount of anode material is required due to the much higher anode consumption rates.

(4) Past experience has shown that as the protective coating deteriorates (or when surface areas of the metallic structure are physically scarred or scraped) more current and variations in current are required. The sacrificial anode system cannot respond to the additional bare area since its current and voltage are limited and cannot be varied.

(5) Due to the buildup of algae, silt, or other deposits on sacrificial anodes, the current output of the anode may be reduced.

(6) Basis of design must consider future and changing conditions of structure surface which is not considered in the design of sacrificial anode and impressed current systems.

(7) Although the sacrificial anode systems require less maintenance than impressed current systems, they nevertheless require some maintenance. Since there is no method to monitor a sacrificial anode system to determine if it is operating in accordance with NACE criteria, except by taking structure-to-electrolyte potential measurements, many times this type of system is neglected, resulting in damage to the structure.

Chapter 6
System Design, Construction, Operation, Maintenance, and Restoration

6-1. Design

For existing structures, a current requirement test should be made to accurately assess the overall system design. The designer should become familiar with the availability and suitability of types of commercially manufactured anodes which would satisfy the system requirements for cathodic protection. Chapter 5 provides guidance for selecting impressed current and sacrificial anode systems. The designer should become familiar with manufacturer recommendations for use and product performance claims. CPS's should be designed to attain and maintain a level of protection of the structure as defined in the section "Criteria and Other Considerations for Cathodic Protection" in NACE RP0169-96. In order to achieve this level of protection, design calculations must be made to determine the number and types of anodes required. Examples of calculations can be found in Appendix B of this manual for impressed current cathodic protection design, in ETL 1110-9-10 for cathodic protection systems using ceramic anodes, and in MIL-HDBK-1004/10, "Electrical Engineering Cathodic Protection," a handbook developed from evaluations, surveys, and design practices of the Naval Facilities Engineering Command, other Government agencies, and the private sector. MIL-HDBK-1004/10 can be a useful tool for design calculations in conjunction with the criteria that follow. These calculations must take into consideration the total area of the structure to be protected, the resistivity of the electrolyte, the present condition of the protective coatings on the structure, the predicted deterioration of these coatings due to physical damage, the normal paint change of state over a 20-year period, and the environment to which the structure will be subjected. The design of CPS's should be accomplished under the supervision of a certified NACE corrosion specialist, a cathodic protection specialist, or a professional engineer licensed in corrosion engineering.

a. Criteria. NACE International criteria for protection for steel and cast iron piping, covered under paragraph 6.2.2 and subparagraphs of NACE International RP0169-96, should be met for design of civil works hydraulic structures. Those criteria are specifically included here by reference.

b. Guide specification. Guide Specification CW-16643, "Cathodic Protection Systems (Impressed Current) for Lock Miter Gates," should be used in preparing contract documents for procurement of CPS's. This specification, in addition to providing the technical requirements for various items of equipment for the CPS, addresses methods for protection from ice and various debris of the string anodes and the electrical leads to the button and string anodes. This specification is based upon the use of impressed current systems, which are normally used on hydraulic structures having large areas requiring corrosion protection. Button-type anodes are normally used on the skin plate side of the gate with string-type anodes installed in the compartment areas of the gate; however, button-type anodes may also be used in the compartment areas.

c. Zebra mussel guidance. In areas with potential for zebra mussel infestations, the CPS components may be at risk of failure or disruption. Design considerations in preventing these infestations should be included. For control strategies, refer to Zebra Mussel Research Technical Note ZMR-3-05, compiled by the Zebra Mussel Research Program at Waterways Experiment Station, Vicksburg, MS.

6-2. Construction

Installation of a CPS by a construction contractor should be accomplished under the supervision of an NACE International corrosion specialist, senior corrosion technologist, or cathodic protection specialist or a licensed corrosion engineer.

a. Services of corrosion engineer. The construction contractor should be required to obtain the services of a licensed corrosion engineer to supervise the installation and testing of the CPS. The term "corrosion engineer" refers to a person who has knowledge of the physical sciences and the principles of engineering and mathematics, acquired by professional education and related practical experience, and who is qualified to engage in the practice of corrosion control on metallic structures. Such person may be a licensed professional corrosion engineer or may be certified as being qualified by NACE International if such licensing or certification includes suitable cathodic protection experience.

b. Workmanship. All material and equipment shall be installed in accordance with the requirements of the specifications and as recommended by the corrosion engineer and approved by the Contracting Officer. The installation, including testing, should be performed by an organization that has had at least 3 years experience in this type of work.

6-3. Operation and Maintenance

The reliability and effectiveness of any CPS depend upon the manner in which it is operated and maintained, as well as its proper design and installation.

a. Performance. The primary purpose for testing of a CPS is to determine if it has been optimized in accordance with and effectively meets design criteria. A system that does not meet this criteria will not adequately protect the structure against corrosion.

b. Operations and maintenance manual. An operations and maintenance manual should be provided for each CPS installed. This manual should provide instructions for testing and optimizing the system and should specify test equipment required. Copies of the structure-to-electrolyte potential measurements, obtained by the contractor at the time of acceptance of the system by the Government, should be included for reference. Blank data sheets should be provided for Government test personnel to record data obtained in future periodic testing of the CPS.

c. Troubleshooting guide. A troubleshooting guide should be provided for use with the CPS. This guide should address possible symptoms associated with failure of various items of equipment of the system. Recommendations and possible solutions should also be included. If a problem cannot be resolved by the corrosion protection coordinator, then it is recommended that the designer seek the assistance addressed in Chapter 3 of this manual.

6-4. Restoration

Existing inoperable CPS's should be restored whenever possible and feasible. Restoration of a CPS should be part of the corrosion mitigation plan and should include, but not be limited to, the following:

a. A list of materials and cost.

b. An assessment of impact protection and consideration of the need for additional impact protection devices.

c. A survey indicating the status and functional condition of rectifiers, anodes, terminal cabinets, anode system cables, and impact devices.

d. A copy of the latest structure-to-reference-cell potential readings.

Chapter 7
Training and Services

7-1. Training

Training should be provided for project designers, inspectors, and operation and maintenance personnel who are responsible for CPS's in use at projects. Corrosion protection coordinators should arrange with District Training Coordinators for this training. The training should include both cathodic protection generally and report preparation. A PROSPECT course on corrosion control is offered annually for district personnel. The course provides the required CPS training on design and testing.

7-2. Services

Services are available on a cost reimbursable basis to assist districts in training personnel and testing systems. Services are also available for design, restoration, construction, operation and maintenance, and optimization adjustments of CPS's. Services inquiries may be referred to CECW-ET, HQUSACE.